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A Study on the Contributing Factors of Major Landslides in Malaysia

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Abstract

Landslide is one of the most prominent geo-hazard that accounts for colossal losses every year. The contributing factors of landslides in Malaysia are reasonably different from rest of the world. According to a study, the most dominant factor that catalysis the slope failure in many countries of the world is geological conditions. However, in case of Malaysia; most of the landslides occur as a consequence of flawed design, improper construction and non-maintenance of slopes which correlates with the human errors. The statistics of Malaysia shows that highest number of landslides took place in 1996 with 71 cases which is followed by 68 cases in 1995. According to the findings of Highland Towers (1993) landslide, the main causes of failure were inaccuracies in design, poor supervision during the construction and inadequate drainage system. Similarly, in case of Taman Hillview and Bukit Antarabangsa landslide, it has been revealed that improper design practices and poor drainage system supplemented with prolonged rain were the significant causes of the cataclysm. Therefore, based on the investigations on retrospective landslides, this study proposes to incorporate Human Reliability Assessment technique as a part of working strategy for slopes along with strong adherence to the design guidelines in order to minimize the likelihood of landslides.

Keywords: Landslide; Geological Conditions; Flawed Design; Improper Construction; Non-Maintenance; Human Errors.

1. Introduction

A natural disaster, by its nature is always multifaceted and unpredictable. Landslide is one of the major geo-hazard accompanied by uncertainties that give rise to hundreds of deaths worldwide every year. Problems of landslides often occur due to instability of slopes, distressed slopes, and cut slopes [1]. In Hong Kong, it is reported that on an average hundreds of landslides occur every year due to old slope failures. These are cut and fill slopes. Cut slopes are commonly 40–70^o, and fill slopes are 30–35^o. Because of the lack of geotechnical control, and because most of the slopes are subject to severe deterioration, they are susceptible to failure, particularly during the rainy season, when severe rainstorms are associated with tropical typhoons or low-pressure troughs [1]. The first use of the term 'landslide' was recorded in 1838 by J. D. Dana, and it may be the earliest classification of landslides [2]. The term "landslide" describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing (Table 1).

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Table 1. Landslides and its movements [3]

Movement type		**Material classification**		
		Bed rock	Engineering soils	
			Mainly coarse	Mainly fine
Falls		Rock fall	Debris fall	Earth fall
Topples		Rock topple	Debris topple	Earth topple
Slides	Rotational	Rock slide	Debris slide	Earth slide
	Translational			
Lateral spreading		Rock spread	Debris spread	Earth spread
Flows		Rock flow	Debris flow	Earth flow

According to Cruden [2], "Landslide is defined as rock or debris movement or slope earth down". Ground characteristics, sub surface soil properties, quick variations in ground water table along the slope easily trigger the landslides. The causes of slope failure belong to three main groups:

- Sub soil strength: Steep and high slopes require more strength to uphold as compared to low or medium height slopes. With the passage of time, sometimes, the soil becomes weak and this also gives rise to instability.
- Pore water pressure: In peak monsoon seasons effective stress decreases, which lowers down the shearing resistance at the slip surface. That is why slope fails after heavy downpour.
- External impacts: Earthquake forces, scouring, and wrong cutting at the toe put the slope at the verge of failure. These categorizations are in actual the work of Bromhead [4].

Varnes [3] recognized that it is the chain of events from "cause to effect" that happens in slope movements. When preparing a Landslide Report for a particular site, of primary importance is the recognition of the conditions which caused the slope to become unstable and the processes which triggered that movement. Only an accurate diagnosis makes it possible to properly understand the landslide mechanisms and thence to propose effective remedial measures [5]. The diagnosis is essentially dependent on the causes of landslide which could be either geological, morphological or human (Table 2).

In comparison with the contributing factors, there is usually one dominant factor that triggers the landslides at the time of failure. It may be intense rainfall, snow melt, variations in water level, volcanic eruption, earthquake tremors or slope geometry change. On the other hand, it should also be noted that in some cases, landslides may occur without an apparent triggering factor but numerous causal factor [6]. The terms of causal factors, preparatory factors and contributing factors are used interchangeably by many researchers; however their definitions are same [3, 5, 6].

Table 2. Causes of landslides [7]

Geological Causes	**Morphological Causes**	**Human Causes**
Poor/Susceptible materials	Weathering effects Freeze/thaw shrink/swell	Digging of slope
Splitting, Jointing, Shearing in materials	Techtronic/Volcanic pressure	Pumping out Leakages, Irrigation Mining
Negatively acquainted (Faults/Bedding etc.)	Accumulation loading slope/crest	Cutting of forests
Contrast to permeability, Material stiffness	Piping/Erosion Removal of vegetation	Encroachments on slopes

2. Objectives of the Study

The objectives of the study are:

1- To study the contributing factors of major landslides in Malaysia

2- To explore the retrospective events of landslides in Malaysian region

3- To investigate and present the details associated with each landslide event.

3. Contributing Factors of Landslides

This section highlights the factors that originate landslides. Apart from Malaysia, selective representative literature review and case studies were also conducted with references to countries such as China, Italy, Thailand, Australia, Indonesia, Russia, Taiwan, Greece, Brazil, Germany, Korea, Japan and the United State of America [6].

If specifically referring to contributing factors of Malaysian landslides, their statistics and types differ as compared to worldwide statistics. On worldwide basis, under the category of causal factors, ground conditions are major contributors but for Malaysian region; design errors are dominating (Figure 1 and 2.) [6]. Gue and Cheah claimed that inadequacy in design is normally the effect of lacking in understanding the subsoil conditions and geotechnical issues. Regarding construction failures, Gue and Cheah reported that either the workmanship, materials and/or short of supervision contributed to 8% of the total cases of landslides. About 20% of the landslides investigated are caused by a combination of design and construction errors. For landslides in residual soil slopes, the slope failures caused by geological features only account for 6% which is same as the percentage contributed by a lack of maintenance. It is also mentioned by Gue and Cheah that the geological features, such as discontinuities in residual soils particularly sedimentary formations are not easy to identify. Most of these geological features can only be noticed after exposing the slopes during excavation. In this context, it is suitable to take out confirmatory geological slope mapping of the exposed slopes after excavation by an experienced engineering geologist or geotechnical engineer to spot any geological discontinuities that may contribute to potential failure mechanisms, namely planar sliding, anticline sliding, active-passive wedges, etc. [8].

In case of triggering factor comparison, for Malaysia, rainfall has a major contribution of 58% and it acts as a main triggering factor due to 2550 mm of rainfall per year. After rainfall, loading change contributes to 35% in Malaysian region but for other countries, loading change is very minimal only i.e. 8% (Figure 3 and 4.) [6].

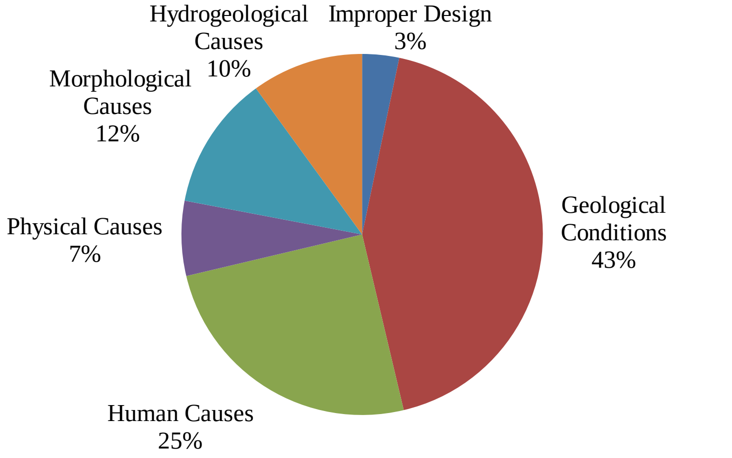

Figure 1. Contributing factors of landslides for selected countries other than Malaysia [6]

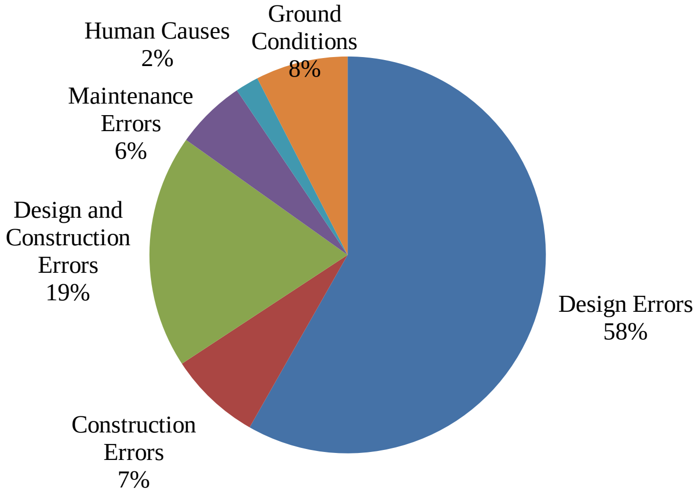

Figure 2. Contributing factors of Malaysian landslides [6]

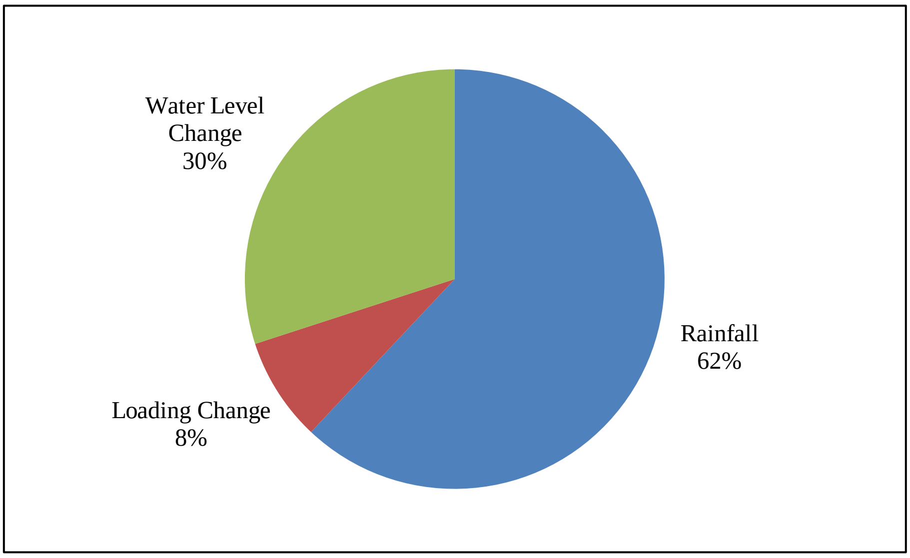

Figure 3. Contributing factors of landslides for selected countries other than Malaysia [6]

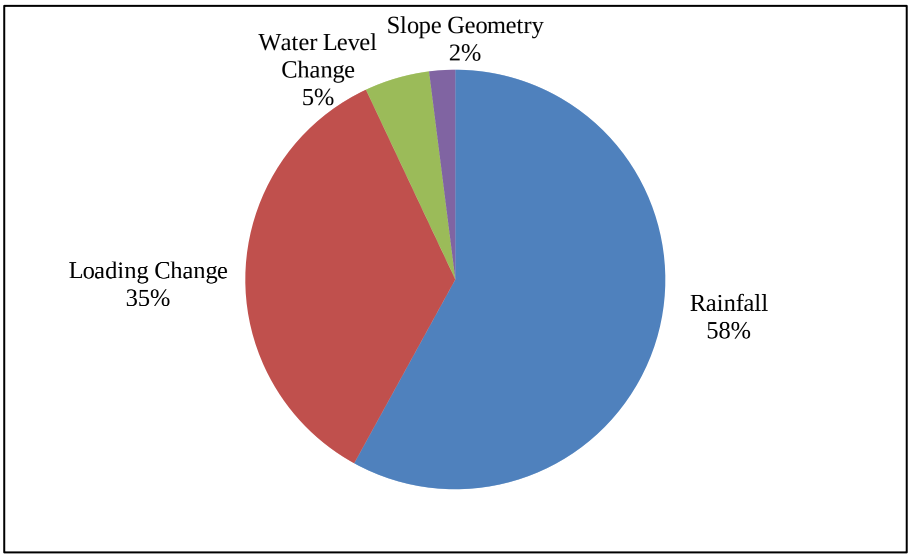

Figure 4. Contributing factors of Malaysian landslides [6]

4. Overview of Landslides in Malaysia

Malaysia is located in the Southeast of Asia, occupying about 330200 km^2. The entire country is divided into two main regions, namely Peninsular Malaysia and East Malaysia. Peninsular Malaysia is in south of Thailand and north of Singapore; while East Malaysia is at the northern one-third of the island of Borneo adjoining Indonesia and Brunei. Its position give it a steamy climate – hot and humid throughout the year – with yearly monsoons from the southwest from April to October and from the northeast from October to February.

The general geology of Kuala Lumpur has been well studied. The bedrock geological map of Kuala Lumpur indicates that the heart of the city is dominated by Kenny hill formation. In simple soil descriptions, it mainly consists of sandy clay or clayey silt, According to Mohamed and associates [9], Kenny Hill formation is one of the typical sedimentary rock formation widely found within the vicinity of Kuala Lumpur and Klang valley, dominated by interbedding of sandstone, siltstone and shale. On Kenny hill formation, it is noted that sharp topography, intense nomadic rainfall and deep tropical weathering are contributing fully for slope failures [9].

In a report “National Slope Master Plan (2009-2023)”, the first reported landslide of Malaysia was in December 1919 which claimed 12 lives. Another incident took place in 1961 at Ringlet Cameron Highlands. Jaapar [10] gathered very extensive data of Malaysian landslide. However, this chapter only discusses those major landslides which occur after 1990. A total of 49 cases of large landslides are reported, out of which 88% are attributed to manmade slopes. Large landslides are those which cover more than 5,000 cubic meters [11].

National Slope Master Plan 2009-2023 [12] reflects the cases of massive landslides. A case of Highland Tower Condominium, Hulu Klang, and Selangor is also reported. This incident happened on 11 December 1993. An abrupt collapse of Block 1 due to toppling effect has taken place. Investigations show that the collapse is due to buckling and shearing of rail piles which is activated by soil movement. Retrogressive landslides behind Block 1 are responsible for the progression of soil movement. The prime cause is not only the improper drainage but inadequate designing of slope. Above all factor of safety less than 1 is incorporated in design [13].

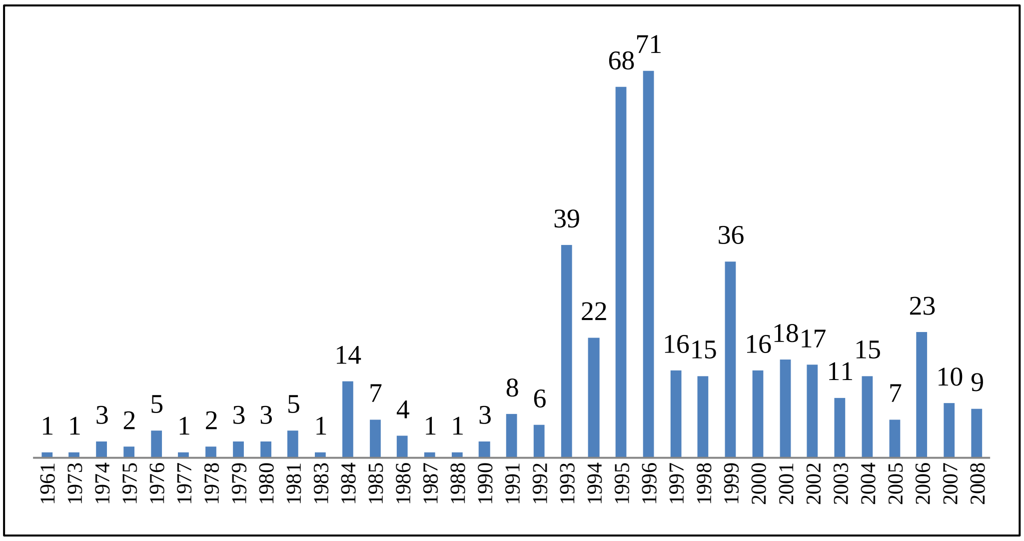

Figure 5. Landslide Events (1961-2008) [14]

A report of JabatanKerja Raya overviewed the losses that occurred due to disastrous landslides. The report mentioned that the highest number of deaths recorded by a single landslide event took place in Sabah on 26 December 1996. Apart from fatalities, few villages were totally destroyed due to debris flow. It is not only the fatalities recorded but the blockage of roads and hindrances in the communication system that disturbed the whole planning and schedule during that particular period. Like North Klang Valley Expressway rockslide in 2003 claimed no lives but posed one of the highest economic losses which also resulted in huge traffic congestion and long-time road closure. It is also spotted that Bukit Antarabangsa landslide has been taken place not only in December 2008 but also once before in 1999. A very recent landslide again brings destruction and economic losses [12].

5. Cases of Landslides

The following case of slope failure discusses the nature and various aspects of the landslides in Malaysian region.

5.1. Serendah (2016)

This recent landslide occurred on 26 November 2016 at Hulu Selangor and investigations are still underway to assess the primary causes of this landslide. The Hulu Selangor official stated that preliminary investigations showed that the landslide, which produced huge sinkhole up to seven metre deep, was triggered by a water movement from the nearby hill [15]. According to the same official, 64 houses in the area were affected by the landslide and 340 residents were ordered to evacuate to an alternate location. He further added that the initial investigation found that the landslide was caused by the swift flow of underground water [16].

5.2. Ukay Perdana (2013)

A landslide event that took place on 03 July 2013 left three workers dead and one injured. This landslide event buried four workers beneath the rubble while others escaped unscathed [17]. According to the official of MPAJ, the occurrence of this landslide could be due to the negligence as there was a complete absence of safety management in carrying out work at site and incident was not related to structural or slope failure. The official also said that based on MPAJ's inspection at the incident site, the accident took place when digging was being carried out until the 3.5 meter earth wall fell, burying workers working below [18]. This assessment shows that the potential cause of this landslide is human negligence rather than the geological reason.

5.3. Penang Hill (2013)

The dreadful landslide event took place in September 2013 at Penang Hill in which 13 landslides had been reported following heavy downpour in the state. The official stated that 3 landslides were reported to be serious at locations

KM2.1, KM2.5 and KM4.0 which suffered massive earth collapse. The official said that weak ailing trees and soil erosion were among reasons behind the landslides and added that loose soil due to continuous heavy rains could have caused the tree to fall, dragging the earth with them [19]. Fortunately, there were no casualties but the landslides resulted in the cost of remedial works to escalate to RM 1 million. Another official pinpointed the reason for this landslide is lack of proper plan by the developers when carrying out their projects in that area which potentially caused the landslide [20].

5.4. Puncak Setiawangsa (2012)

On 29 December 2012, a large slope failure occurred at Puncak Setiawangsa, eastern suburb of Kuala Lampur. Yunus and Ahmad, 2006 [21] indicated that 88 residents of bungalows, shop houses and double-story terrace houses were ordered to move out because of soil movement. According to Azmi et al, 2013 [22], 60 meters high retaining wall was collapsed together with the rear portion of a house. The house later has been demolished to reduce the burden on the hill edge.

The main reason for this landslide is attributed to unsuitable slope protection method used for the hill. According to the expert from Universiti Kebangsaan Malaysia, the wall used to protect the slope was known as shotcrete wall which prevents water from entering the soil. However, water can still seep into the slope from areas not covered by the wall but the wall also prevents water from flowing out. In other words, water can flow in but not out. When this happens, the groundwater pressure builds up and breaks through the wall, causing the landslip [23].

5.5. Bukit Antarabangsa (2008)

A section of slope collapsed at the district of Gombak (UluKlang) Selangor, well known as Bukit Antarabangsa residential area, resulting in fatalities and injuries. The debris from the landslides completely blocked the access road, to the neighboring residential areas, and leaving about 2000 residents trapped without access. The landslide took place at approximately 3.30 AM, on 6th December 2008, measuring about 109 m width at the crest, 120 m in length and 15 m in depth. An estimated of 101,500 cubic meter of earth had translated to a maximum run off distance of about 214 m from the toe of the slope where the soil type is granite residual soil. Mariappan and associates [24] put this landslide into deep seated landslides category. It is usually the repercussion of high pore water pressure that prompts these types of failures. The main contributing factors that have been investigated are [25, 26].

- loose soil from earth dumping on the slope during development
- poorly maintained/damaged drainage on the failed slope and its vicinity soil creeping which initiates or widens existing cracks and forming new tension cracks
- great leaking from running water pipe along an abandoned housing scheme due to soil creep
- Long-standing rainfall during the month of October and November

5.6. Tamam Zooview (2006)

On May 31, 2006 at about 4.30 PM, a landslide occurred at the back of a row of terrace houses located on top of the slope of Taman Zooview. In this incidence, both compensatory and non-compensatory losses have been occurred. Slope stability analysis shows that the factor of safety for localized slope failure found to be 1.05. The slope is thus perching precariously and failure can be expected to happen at any time, particularly with incessant rainfall and poor drainage system [27].

In relation to the ZooView landslides, it is also supported by Samah [28] that nothing in the world is maintenance free and therefore, this statement is also applicable in the hillside development. Less-maintenance will disturb free flowing water on land surface which results in water ponding and later on will affect the stability of the development area. This scenario has happened in the Highland Tower development, as the land become unstable because of water ponding caused by less maintenance activities. In conclusion, from the reported case studies, it is seen that the occurrences of landslides in Hulu Klang are due to the design and construction failure of the retaining wall, lack of maintenance and triggering by rainfall. This shows that suitable design approach in site layout and correct construction method for hillside development are compulsory [28].

5.7. Tamam Hillview (2002)

According to Komoo and Lim [29], this landslide was a multifaceted landslide, i.e. a combination of rotation at the head and sliding in the middle which was followed by a flow happening at the toe. The total length of the landslide was up to 200m and 50m of the surface rupture width, concerning around 25,000m^3 of disturbed slope material. Even though continuous heavy rain triggered the sliding, but there were various other important factors that included phony material prone to failure, geological lineament that facilitated sliding, shape of the old landslide that abetted the build-up of groundwater, levelling and terracing at the upper part of the landslide area, and an old damaged rubble wall that boost up the concentration of surface water. The landslide is, in fact, a return of an old landslide. It is also confirmed through JabatanKerja Raya [6] that inadequate design of the adjacent slope also contributed in this landslide. In view of Samah [28], the landslide carries more or less same causal factors but it lies in a category of debris flow when compared to Highland Towers (1993).

In one of the project undertaken by slope engineering division regarding landslides in Hulu Klang, the main factor of causing slope failure is non-maintenance or poorly maintained drainage facility. The study also highlighted the areas where immediate changes are required to avoid any more incidents. Some of the areas are in urgent need of fixation of drainage facilities to control surface runoff, water ponding and infiltration [30].

5.8. Bukit Antarabangsa (1999)

In May 1999, more than 10,000 residents at Bukit Antarabangsa received an alarm when a few major landslides cropped up and cut off the entree to the road of Bukit Antarabangsa. Fortunately, there were no fatalities. This landslide, Bukit Antarabangsa 1999 in cut and fill slope is basically the outcome of several smaller landslides [10]. The landslide positioned about 100 m to the west of the Wangsa Height condominium. Faisal [31] stated that the volume of the landslide was sketched to be 14,580 $m^{3.}$ The slide had fetched down about 70 m stretch of Wangsa 3 road. Another landslide occurred a day before, (May 14, 1999) at about 4:30 PM, on a steep slope adjoining to the Athenaeum at The Peak condominium. The landslide scar measured about 31m wide of surface rupture and 140m long of centre line, from crown to the toe of the slide. The supersaturated slide debris of about 13,000 m^3 piled up at the toe of the slope; engage an area of about 50 m wide and 100 m long of displaced masses. According to Jaapar [10], Kumpulan Ikram Sdn Bhd reported in 1999 that the most probable causes of slope failure can be attributed to the following factors; the slope has minimum factor of safety 1.00 to 1.35 which is lower than the required factor of Safety 1.4 for slope adjacent to high rise building. The slope was not properly constructed as indicated by the presence of relatively weak material in the body of the slope and there is no warning of berms drain construction within the failed section of the slope.

The other contributing factors are infiltration and ingress of water into the soil during prolonged rainfall, lack of maintenance to the slope in the form of blocked drains and previous un-repaired cracks in drains, deposition loading on the slope by dumping activity, vegetation removal by dumping activity on the slope which increases surface erosion, internal erosion of the base of fill materials due to improper treatment of the original seasonal stream and prolonged rainfall resulting the water table to rise and intercept the ground surface. Spring is formed at the intercepting point, which is actually headwater of seasonal stream flow [10]. In short, apart from rainfall, the following factors are responsible for an incident of Bukit Antarabangsa 1999.

- The slope has a minimum safety factor of 1 to 1.35, not fulfilling the requirement as the required safety factor is 1.4.
- Presence of weak material in the slope body.
- No clue of berms drains construction within the collapsed slope section.
- Blocked drains and previously unrepaired crack signs in drains.
- Internal erosion [10, 31, 32].

5.9. Gua Tempurung (1996)

Around 7.30 AM on 6 January 1996, a section of a cut slope at 303.8 km of the North South Expressway near Gunung Tempurung, Kampar, Perak failed. Two smaller retrogressive landslides took place near the first landslide, with one stirring at 11.20 AM and the other at 12.42 PM. The length of the displaced mass was 82 m. The depth of surface of rupture was 22 m whereas the width of surface of rupture was 65m. The landslide occurred along a shear zone where the rocks are highly fractured, and the landslide site was underlain by granite, schists and hornfels. Soils developed from these rock types have different engineering properties. Although there was no rainfall at the time of the landslide occurrence, it was reported in the press that there was some accumulation of water at the top of the slope due to earlier rainfall [10]. According to Singh and associates [33], it is a deep-seated rotational slide. Despite being strengthened by anchor and guniting, failure of the cut slope has been taken place at the side of North-South Highway.

5.10. Pos Dipang (1996)

The explanation of Komoo [34] about the above event is that the excessive rain triggers the event. The profuse amount of rains, in principally, softened the ground in hilly area which consequently triggered several large landslides on the steep slopes upstream of Sungai Dipang. The debris and mud from the landslide entered the river channel, creating a huge mudflow. Field evidences indicated that one of these temporary dams was formed about 200 m upstream of Pos Dipang. This dam broke due to the increasing force of swelling water, abruptly releasing a huge amount of water and debris, thus give rise to huge debris flood.

About this landslide, JabatanKerja Raya [6] reported that along with the triggering factor of rainfall, inadequate factor of safety is also governing here. It defined that factor of safety is basically not invariant in nature, with the passage of time due to influence of rise in ground water table/pore water pressure; it varies and lowers down. In that situation, the selection of safety factor has to be chosen by taking all the relevant factors into consideration [35].

5.11. Highland Towers Collapse (1993)

On December 11, 1993 at 1.30 PM, after a period of 10 days of incessant rain, Block 1 of Highland Towers Condominium collapsed resulting some fatalities and the loss of use of the remaining two Tower Blocks that are still unoccupied. The findings of local authority [36] set up a Technical Committee of Enquiries and the findings are supported by as follows:

- The Highland Towers Condominium was sited mainly on fill ground over granitic formation. The maximum depth from the ground surface to bedrock is about 19 m. Granitic rocks found in and around the areas were not highly soluble minerals, and therefore, adversely affected the stability of the foundations.
- Soils overlying the granitic bedrock were very loose i.e. loose silty sand and highly permeable.
- The foundation for all the three tower blocks were supported on rail piles designed to take only vertical loads. Cut and fill slopes, rubble walls around block 1 showed inadequate design (carrying safety factor of less than 1) and poorly supervised construction. The buckling and shearing of rail piles foundation are due to soil movement.
- Surface drainage system provided was not in accordance to the approved plan. Situation worsened when earthwork activities changed the drainage pattern on the hill slope behind the condominium blocks and available drainage systems were not maintained.
- Non-maintenance of the drainage facility (leakages from pipe and the culvert carrying diverted flow of East stream).
- Clearing of trees on upper catchments resulted in increased runoff that flowed down the terraced hill-slope immediately behind the towers.
- Retrogressive slides progressively moved uphill starting from loss of toe mass at the back of the condominium block 1 [10, 27, 36].

From the computational analysis done by Nguee [37], it is reported that high wall has very low safety factor and the designed wall would fail at 5 m very easily; even without water pressure. The calculated safety factor of all those walls which were at the back of Block 1 is 1.52 even without considering water forces at the back of the walls. It is also observed during the same study that the wall composed of different size of stones with haphazard plaster carrying no drainage blanket over it.

6. Discussion

The findings of this study unfold that the causes of slope failure are multidimensional and there are many reasons that can contribute to a landslide. From holistic perspective, it is clear that human errors are dominating that contributes to landslides in Malaysia while the geological/morphological causes are infrequent which particularly include rainfall and erosion. The human errors are mainly in the form of improper planning, faulty design, non-maintenance and negligence during the construction. The investigations on Ukay Perdana (2013) landslide reveal that the potential cause of this event is lack of proper planning as the landslide took place when digging was being carried out and no safety practices were adopted which directly relates to the human error. Similarly, along with other landslides, the potential reason for Puncak Setiawangsa (2012) landslide was design inaccuracies in which shotcrete wall was built on metamorphic rock to prevent the water from entering in to soil which is unadvisable due to lack of strength of metamorphic rock. According to the statistics of Gue and Tan, 2006 [38] on causes of landslides in Malaysia, 60% of the landslides occurred due to design errors and only 6% happened due to geological reasons. Therefore, based on findings, this study recommends the use of Human Reliability Assessment technique for mitigating the chances of human errors by addressing their causes and strong adherence with the design guidelines to minimize the likelihood of landslide.

Table 3. List of major landslide incidents

S.No	Landslide	Year	Potential causes
1	Serendah	2016	Swift flow of underground water
2	Ukay Perdana	2013	Negligence in safety precautions/ improper planning
3	Penang Hill	2013	Continuous rainfall/Improper plan by developers in projects
4	Puncak Setiawangsa	2012	Improper design of retaining wall
5	Bukit Antarabangsa	2008	Poor drainage system/long rainfall
6	Tamam Zooview	2006	Design and construction/non-maintenance
7	Tamam Hillview	2002	Heavy rainfall, improper design of slope
8	Bukit Antarabangsa	1999	Rainfall, inadequate design, improper drainage, erosion
9	Gua Tempurung	1996	Geological
10	Pos Dipang	1996	Rainfall, improper design of retaining wall
11	Highland Towers collapse	1993	Rainfall, non-maintenance, design inaccuracies

7. Conclusion

This study demonstrates that the contributing factors of Malaysian landslides are considerably different as compared to many countries in the world. In other regions, geological and morphological causes are common to instigate landslides whereas in Malaysian region; the errors during the design/construction phase along with non-maintenance of slopes mainly lead to the slope failures. The investigations on retrospective landslides in Malaysia shows that human errors which predominantly include design/construction inaccuracies and improper maintenance of slope are the factors that mainly catalyses the landslide. Therefore, this study recommends the application of Human Reliability Assessment techniques as a part of working strategy for slopes to mitigate the chances of human errors while ensuring compliance with the design guidelines and protocols in order to effectively restrict landslide events.

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